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Porosity of Molding Sands*

By

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1. Introduction

Among the quantities representing properties of molding sands, permeability and strength are specially important, and porosity is not taken up in the usual test of sand.[1] But porosity can be measured without any special apparatus, and is one of so concrete quantities that it may give a clue to throw light on the real character of sands. So we measured porosities of several kinds of molding sands.

2. Method of measurement

Porosity was measured by the method used in the field of ceramic industry. That is, a quantity of sample sand is taken in a graduated glass tube, which is let to fall repeatedly from a constant height to the top of a desk. The volume of the sand is read and the bulk density D is obtained. On the other hand the true density of the sample S is measured by means of a picnometer. Then porosity P is given by the following equation :

$$P=\left(1-\frac{D}{S}\right)\times 100 \quad (\%).$$

The graduated tubes used in our case in the measurement of bulk density were of 6mm (tube A) and of 1.6cm (tube B) in diameter. And the amount of sample taken in the tubes was about 1g when tube A was used, and 10~15g when tube B was used.

The values of porosity of the same kind of sand measured with tube A and measured with tube B are not equal. That is, the porosity is dependent on the diameter of the tube used as well as on the amount of sample taken in. So the absolute value of porosity measured by this method has little meaning, but we can compare the relative porosity of different kinds of sand by this method with the same tube. It seems that when a thicker tube and larger quantity of sand are used, the change of volume of sand by falling is read more accurately, but as the upper surface of the sand does not become plane because of its large cross section, the error on reading the volume is larger.

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3. Samples

The samples were sixteen kinds of molding sands offered by three foundries in this prefecture. They are shown in Table I. And the microphotographs of them are shown in Plate I and II. All the samples were dried for an hour at 105°C, and then left in the room.

Table I

Number	Sand	Foundry
1	Gosho-zuna (御所砂)	C
2	Shôwa-zuna (昭和砂)	C
3	Facing sand (contains graphite and bentonite)	B
4	Facing sand	C
5	Back sand	B
6	Noma-zuna (野間砂)	C
7	Facing sand	B
8	Old sand (used for two months)	C
9	Silica sand	A
10	Kama-zuna (釜砂)	C
11	Silica sand	A
12	Silica sand	C
13	Shore sand	C
14	Zircon sand	A
15	Synthetic sand for aluminium alloy	C
16	Hôwa-zuna (豊和砂) for copper alloy	C

4. Results

Fig. 1 shows the values of porosity of all samples measured with tube A plotted against the number of fallings. The tube A was used because the sample No. 14 was not so plentiful. At the beginning of repeated fallings the porosity decreases rapidly, and at about four hundred times of fallings, it settles down in a constant value. From the standpoint of the values of porosities, the samples could be classified into next four groups : (1) The sands from No. 1 to No. 8 having large porosities are the kind of hill sand. (2) The sands from No. 9 to No.13 are the kind of siliceous sand. (3) The sand No.14, zircon sand, has exceptionally small porosity. (4) The sand No.15 and No.16 show large change of porosity in their initial and final states.

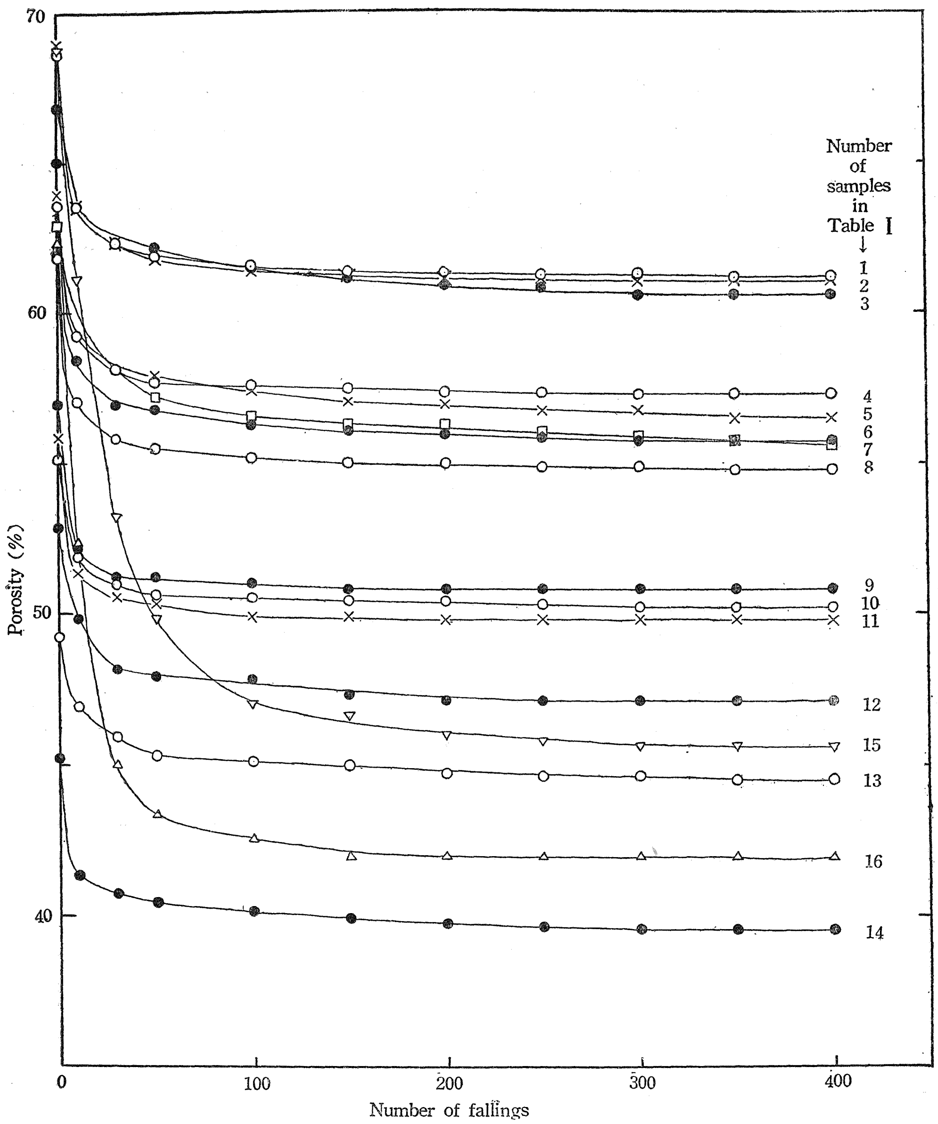

Fig. 1 Porosity of samples

5. Discussion

Among the factors, on which porosities of samples depend, their fineness must be taken into account at first. For example, in the silica sand samples, the sand No. 9 is the finest, and No.11 and No.12 are coarser in order, as seen in Plate II, while the porosity of No. 9 is the largest and those of No.11 and No.12 are smaller in order. This fact seems to show that, as for the sands of the same kind, the finer sand has the larger porosity. But between the fineness and the porosity of different kinds of sand there exists no such simple relation.

Secondly the influence of grain shape of sands may be considered. As seen in Plate I and II, the sands No.1~8 having large porosities are mostly subangular shape and the sands No. 9~13, 15 and 16 are generally angular. But the sand No.14 having still smaller porosity is rounded. The fact that the porosity of the sand No.14 is exceptionally small compared with other sands, may depend on its very large true density 4.66g/cm^3, compared with those of other sands about 2.6g/cm^3, and also as seen in Plate II, on the uniformity and the roundness of grains.[2] But for the other sands, the relation between the grain size and the porosity can not simply be concluded.

Thirdly, as seen in Plate I, the sands No. 1~8 having large porosities contain fine clay particles, which attach to the sand grains and take complex size. The sand No. 3 made by adding graphite and bentonite to the No. 7 has far larger porosity than No. 7. The sand No.10 is a natural mixture of relatively coarse silica sand and clay, and its porosity is larger than that of coarse silica sand No.12. Therefore as a guide it may be considered that to contain clay in this kind of sands makes their porosity larger. To verify this point furthermore we removed clay from the samples No. 1, 2 and 6, and measured their porosities. To remove clay, according to clay content measuring method of usual molding sand tests, we took away the particles, of which the falling velocities in water are smaller than one inch per minute. The porosity of the sand and that after clay is removed are shown in Fig. 2. From this it will be seen that the porosities decrease as clay is removed.

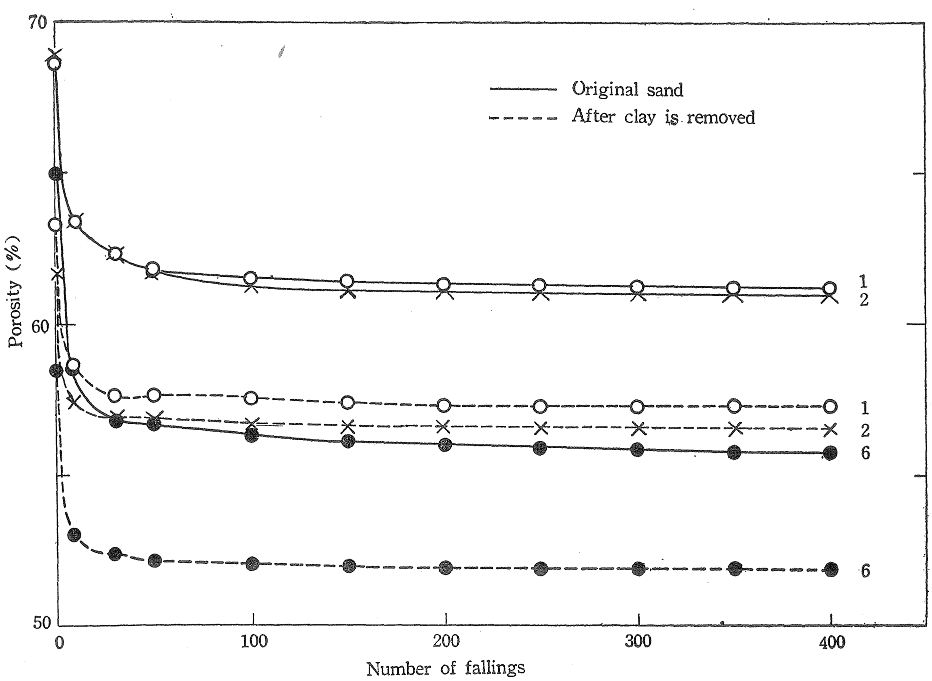

Fig. 2 Effect of clay content.

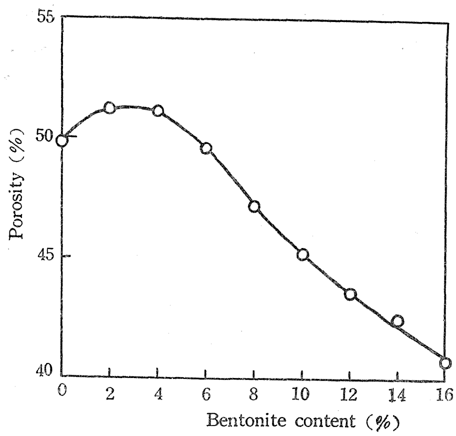

Fig. 3. Effect of adding bentonite to silica sand.

For some other kind of sand, however, porosity does not always increase monotonously as clay content is increased. Fig. 3 shows porosities of the samples made by adding bentonite to No.11 silica sand. Ordinate shows the porosity after four hundred times of fallings, which has maximum at about 3 % of bentonite content, and rather decreases for higher content.

6. Analysis of the curves of porosity versus number of fallings

Not only the porosities but also the behavior or forms the porosity to decrease with number of fallings are different with samples, as seen in Fig. 1. This behavior is considered to be related to flowability of sands. So we shall make some consideration on this form of decrease of porosity.

Fig. 4 is a sketch of a curve in Fig. 1. With number of fallings N, porosity P decreases from its initial value P_0 and approaches to a constant final value P_∞. Now consider a sand at a state denoted by the point A. This sand has "pores which can decrease" till it attains to the final state, that is $P-P_\infty$. Then it seems reasonable to assume that the rate of decrease of porosity with shock of falling $-dP/dN$ is a function of $P-P_\infty$, and indeed its increasing function. So we put

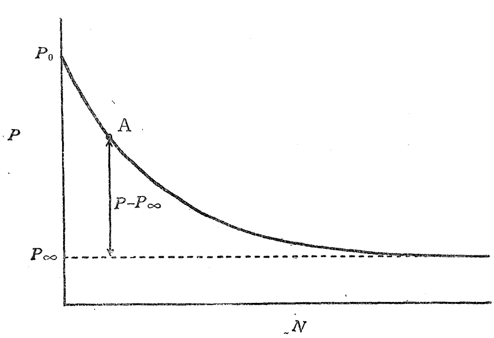

Fig. 4

$$-\frac{dP}{dN}=k(P-P_\infty)^n,$$

where k and n are positive constants. These constants k and n show the form of decreasing of porosity.

The values of these constants are found as follows. We find $-dP/dN$ by graphically differentiating an experimentally obtained curve similar to Fig. 4, and plot $\log(-dP/dN)$ versus $\log(P-P_\infty)$. Then we get a nearly straight line. Fig. 5 is an example obtained for the sample No. 5. The gradient of this straight line gives n, and the point at which the straight line cuts the ordinate gives k. To perform such an analysis, a precise curve having more points of measurements than that in Fig. 1 is needed, so the data obtained from the measurement with tube B were chosen. Accordingly, k and n for the sample No. 14 were not obtained. The values of k and n thus obtained are shown in Fig. 6. As the axis of k, logarithmic scale was adopted. Though the points in Fig. 6 are widely scattered, still we can see the tendencies that the values of n about 2.5 are frequent, and that the samples having large k have small n and vice versa.

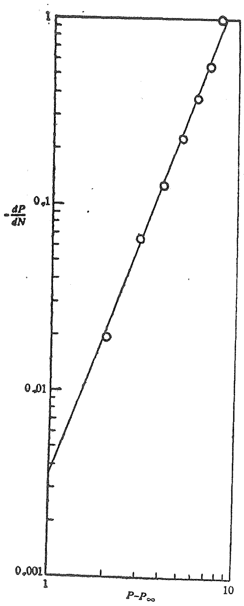

Fig. 5 $\log(-dP/dN)$ versus $\log(P-P_\infty)$ for No. 5 sand.

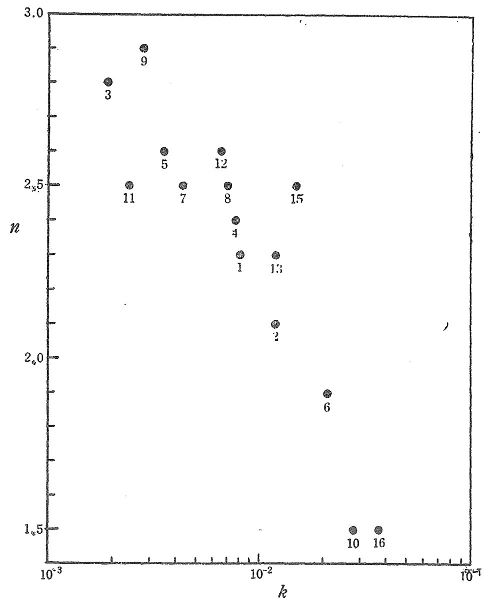

Fig. 6 k and n of samples.

7. Change of porosity by heat treatment

At last, we tested how the porosity changes by firing samples at high temperatures. Samples were heat treated or fired at 300°C, 500°C and 800°C, but those fired at 300°C or 500°C showed no change larger than experimental errors. The porosities after 400 times of fallings of samples held at 800°C for an hour then cooled slowly to room temperature and left there are compared with those of not heat treated ones (already shown in Fig. 1) in Table II. Some samples show little change and some other samples smaller porosity by firing. But these are rather exceptions. For most samples the porosity of heat treated sand is larger than that of not heat treated. We shall next consider the reason for this result.

Table II

Number of sample	Porosity (%)		
	Heat treated	Untreated	Difference
1	61.6	61.2	0.4
2	63.2	61.1	2.1
3	60.5	60.6	−0.1
4	58.1	57.3	0.8
5	57.7	56.5	1.2
6	57.6	55.8	1.8
7	56.8	55.6	1.2
8	55.4	54.8	0.6
9	50.3	50.8	−0.5
10	49.0	50.2	−1.2
12	47.2	47.1	0.1
13	43.8	44.5	−0.7
15	47.2	45.6	1.6
16	43.0	41.9	1.1

For all samples except silica sand, heat treated sand is tinged with red perhaps because of iron oxide, but grain fineness, grain shape and clay content change scarcely. So these factors can not give account for the above result. There is one thing which changes largely by firing, that is moisture content. As stated above, all samples were left in air at room temperatures after drying or firing, so they have adsorbed water vapor and other gases in atmosphere on their grain surface. Measuring the content of these adsorbed gases, shown in Table III, it is known the heat treated sand to adsorb less amount of gases than untreated one. It is difficult theoretically to connect this small gas adsorbing ability and large porosity, but we may suppose that there is some relation between these two quantities.

Table III

Number of sample	Quantity of adsorbed gas (weight %)	
	Heat treated	Untreated
1	0.58	2.37
2	0.61	2.35
3	0.34	1.11
4	0.33	1.11
5	0.33	1.07
6	0.39	1.35
7	0.27	0.86
8	0.33	0.78
9	0.02	0.03
10	0.26	1.00
12	0.03	0.05
13	0.17	0.40
15	0.37	0.65
16	0.15	0.33

From the third column of Table III, it may be seen that for untreated sand the sample having large porosity has large ability of gas adsorption. But this gas adsorbing ability depends not only on the physico-chemical nature of grain surface, but also largely on grain fineness and clay content (i. e. true surface area of grains), so we can not simply connect moisture content and porosity between samples of different kinds.

8. Summary

1) Porosities of several kinds of molding sand were measured.

2) Generally, the porosity of sand belonging to hill sand is larger than that belonging to siliceous sand. It is related with clay content. For the sands of the same kind, the finer sand has the larger porosity.

3) Two constants which represent the form of decreasing of porosity by shock of falling were defined and their values were determined.

4) For most samples, sand fired at high temperatures has larger porosity than untreated sand, and it may be related to gas adsorbing ability.

Acknowledgment

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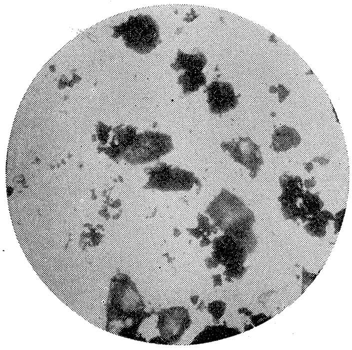
References

(1) Bradley H. Booth : Transactions of the American Foundrymen's Society, **58** (1950) 52.
(2) William H. Moore : ibid., 650.

Plate I



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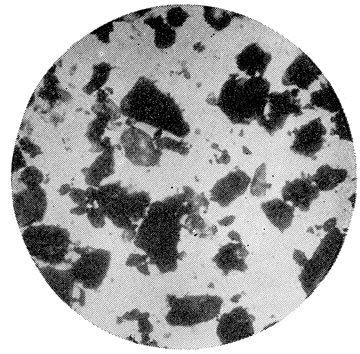

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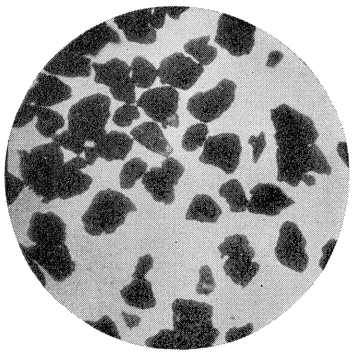

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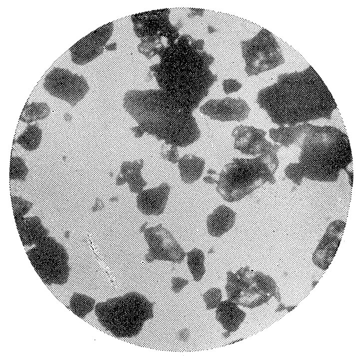

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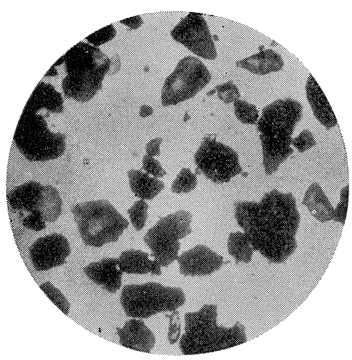

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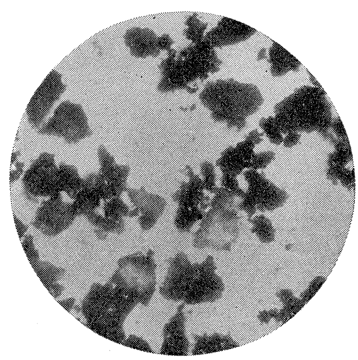

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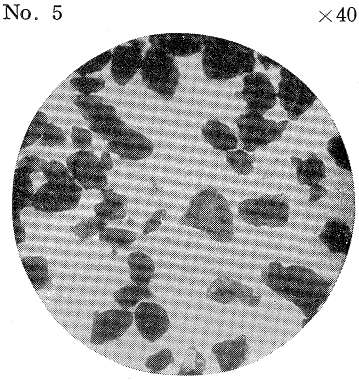

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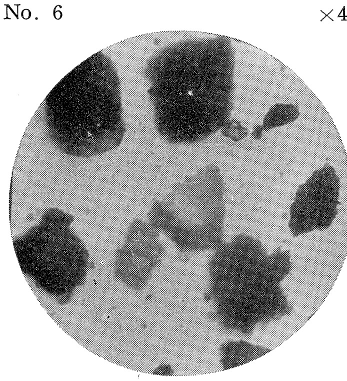

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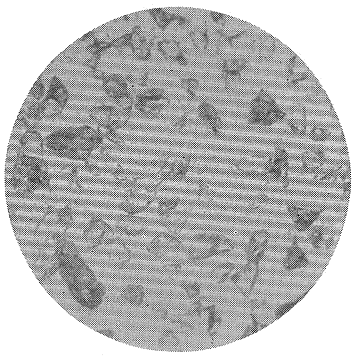
Plate II



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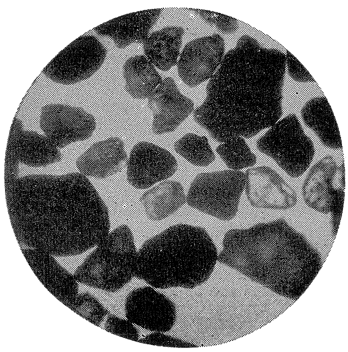

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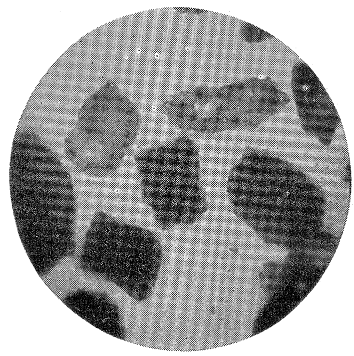

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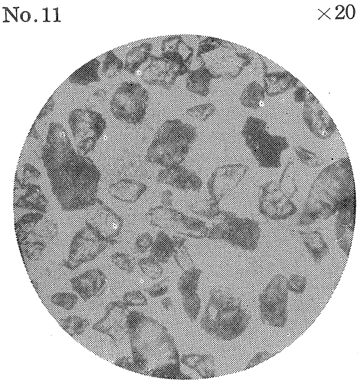

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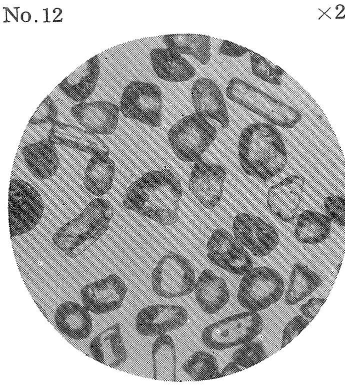

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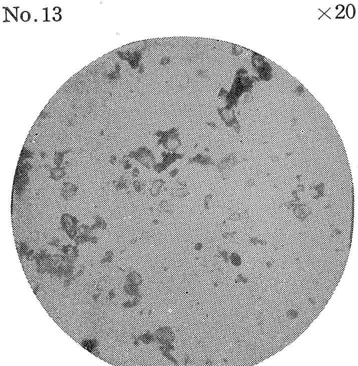

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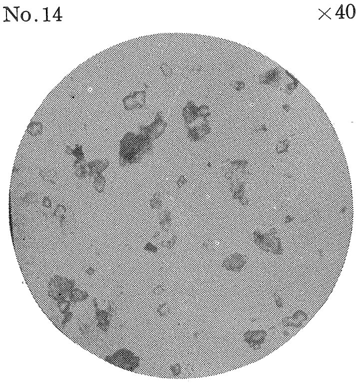

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